STRUCTURAL DESIGN - I

14. Design for Bond

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Bond in Reinforced concrete

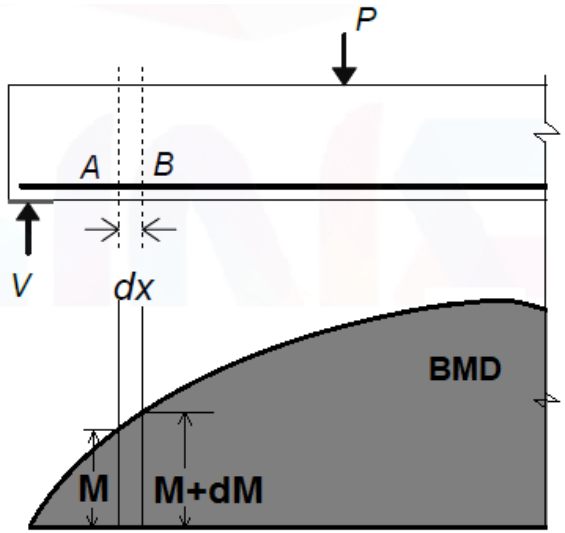
Definition:

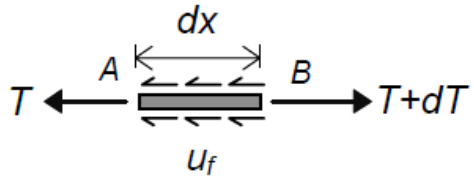
- It refers to adhesion between Reinforcing steel and the surrounding concrete.
- It is responsible for the transfer of axial force from Reinforcing bar to the surrounding concrete (therefore, ensures *strain compatibility*).
- **Force-transfer Mechanism:** When the flexural member is loaded, force in the steel bars gets transferred to surrounding concrete, by development of tangential (shear) stress along the interface. This is known as **Bond stress**.
- If bond is inadequate, slippage occurs between concrete & steel. As a result, the Euler-Bernolli assumption ceases to satisfy.
- There are 2 types of bonds:
  1. Flexural bond or Local bond
  2. Anchorage bond or Development bond

Types of Bond

1. Flexural bond/Local Bond:

- **Flexural bond stress / Local Bond stress (u_f)** is that which arises in flexural members on account of shear or a variation in bending moment. Evidently, flexural bond is critical at points where the shear (V = dM/dx) is significant.





This difference in bending moment 'dM' between adjacent sections cause a shearforce V= dM/dx in the segment AB. This shear stress in the vertical plane induces shear stress in the horizontal plane, known as complimentary shear stress. This will manifest as Flexural bond stress.

- Flexural Bond stress u_f , uniformly distributed over the steel-concrete interface, is given by:

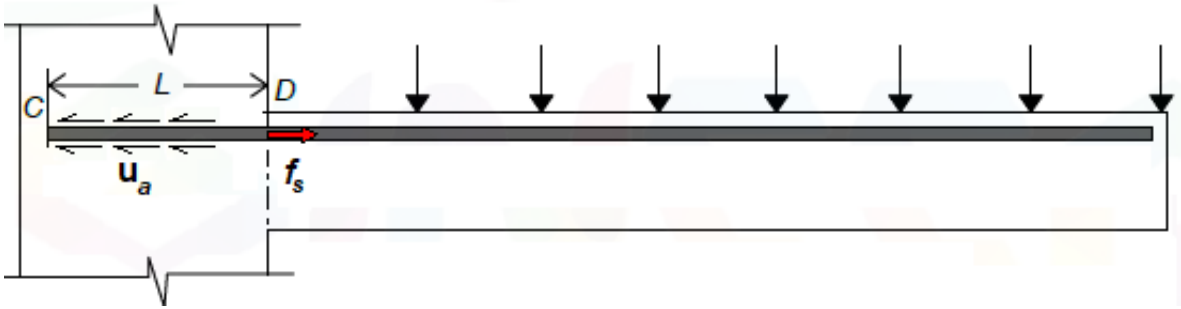
$$u_f = \frac{dM/dx}{(\sum o)z}$$

where $\sum o$ is the total perimeter of the bars at the beam section, and z is lever arm.

Types of Bond

2. Anchorage Bond/Development Bond:

- **Anchorage bond stress / Development bond stress (u_a)** is the stress developed in steel bars at the extreme ends or at cutoff points.
- See the cantilever beam shown below.



- The steel bar is under tensile stress f_s, it should not be terminated at section D, where maximum bending moment occurs. This is because, stress developed at the end of a steel bar is zero.
- Hence, it must be extended further to section C, such that the bond stress between concrete and the additional length of bar L resist the tensile stress f_s in the bar.

$$(\pi\phi L)u_a = (\pi\phi^2/4)f_s \qquad \Rightarrow u_a = \frac{\phi f_s}{4L}$$

where ϕ is the diameter of the bar and L is known as Embedment Length.

Development Length

Codal Provisions:

- **Development length / Anchorage Length (L_d)** refers to the certain minimum length of the bar (under fully stressed condition, i.e., $f_s = 0.87 f_y$) additionally required on either sides of the point of curtailment, to prevent the bar from pulling out under tension (Refer Cl. 26.2.1).

26.2.1 *Development Length of Bars*

The development length L_d is given by

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$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}}$$

where

ϕ = nominal diameter of the bar,

σ_s = stress in bar at the section considered at design load, and

τ_{bd} = design bond stress given in **26.2.1.1**.

26.2.1.1 Design bond stress in limit state method for plain bars in tension shall be as below:

Grade of concrete	M 20	M 25	M 30	M 35	M 40 and above
Design bond stress, τ_{bd}, N/mm^2	1.2	1.4	1.5	1.7	1.9

For deformed bars conforming to IS 1786 these values shall be increased by 60 percent.

For bars in compression, the values of bond stress for bars in tension shall be increased by 25 percent.

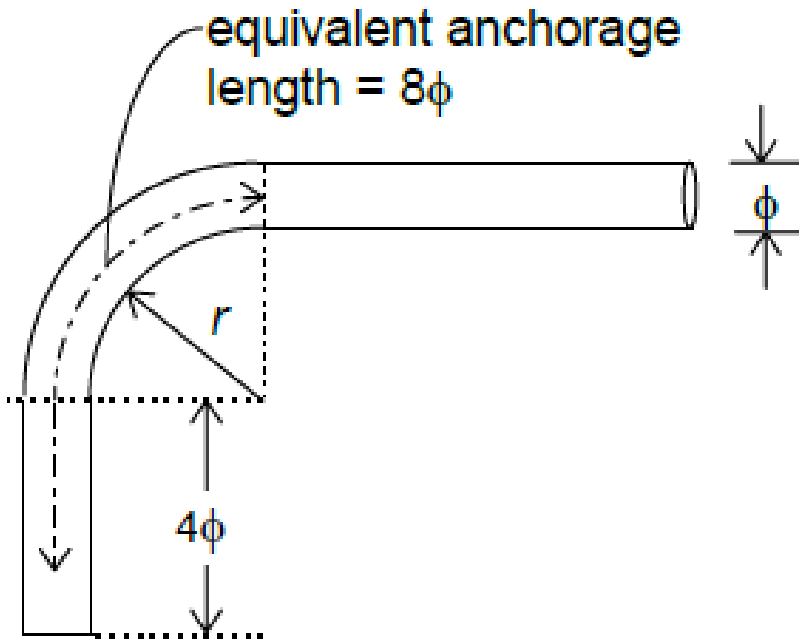
Bends, Hooks & Mechanical Anchorages

- When the required bar embedment cannot be conveniently provided due to practical difficulties, any of the following methods may be adopted. [Refer Cl. 26.2.2]
  1. Bends
  2. Hooks
  3. Mechanical Anchorages

Bends, Hooks & Mechanical Anchorages

Bends:

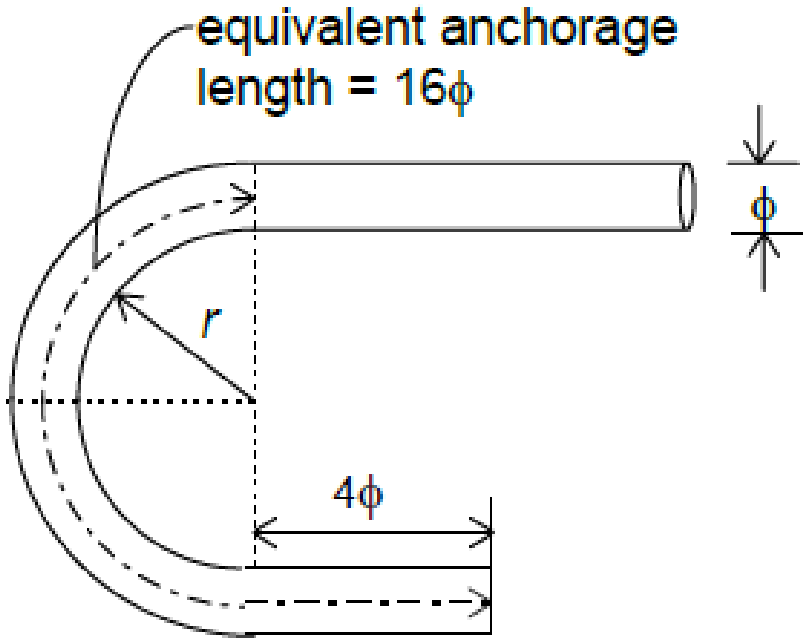
- The anchorage value (or the equivalent anchorage length) of a bend shall be taken as 4 times the diameter of the bar for each 45^o bend.
- Maximum anchorage value of a bend $= 16\phi$
- A **Standard** 90^o **bend** has anchorage value $= 8\phi$ (including a minimum extension of 4ϕ.)



Bends, Hooks & Mechanical Anchorages

Hooks:

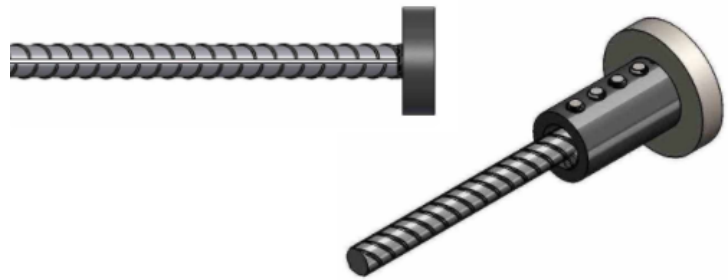
- When the bend is turned around 180°, it has anchorage value = 16ϕ (including a minimum extension of 4ϕ), it is called a **Standard U-type hook**.
- The minimum internal turning radius (r) specified for a hook =
  - 2ϕ for plain mild steel bars
  - 4ϕ for cold-worked deformed bars
- Hooks are generally considered mandatory for plain bars in tension.



Bends, Hooks & Mechanical Anchorages

Mechanical Anchorages:

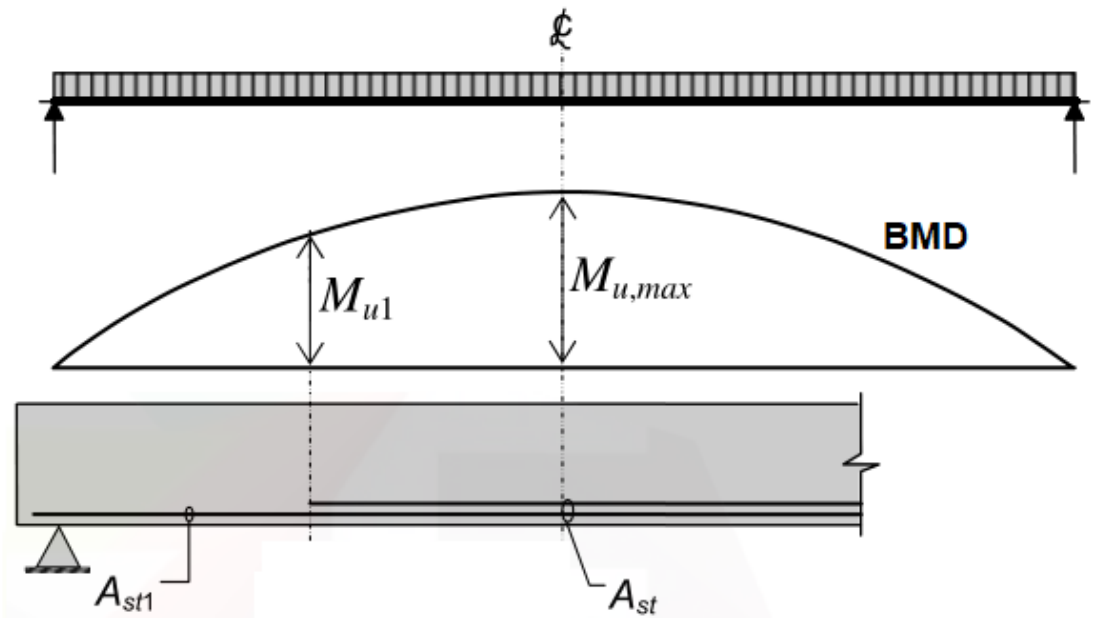
- Mechanical anchorages in the form of welded plates, nuts and bolts, etc. can be used, provided they are capable of developing the strength of the bar without damage to concrete (to be ascertained through tests).



Curtailment of Tension Reinforcement

Definition:

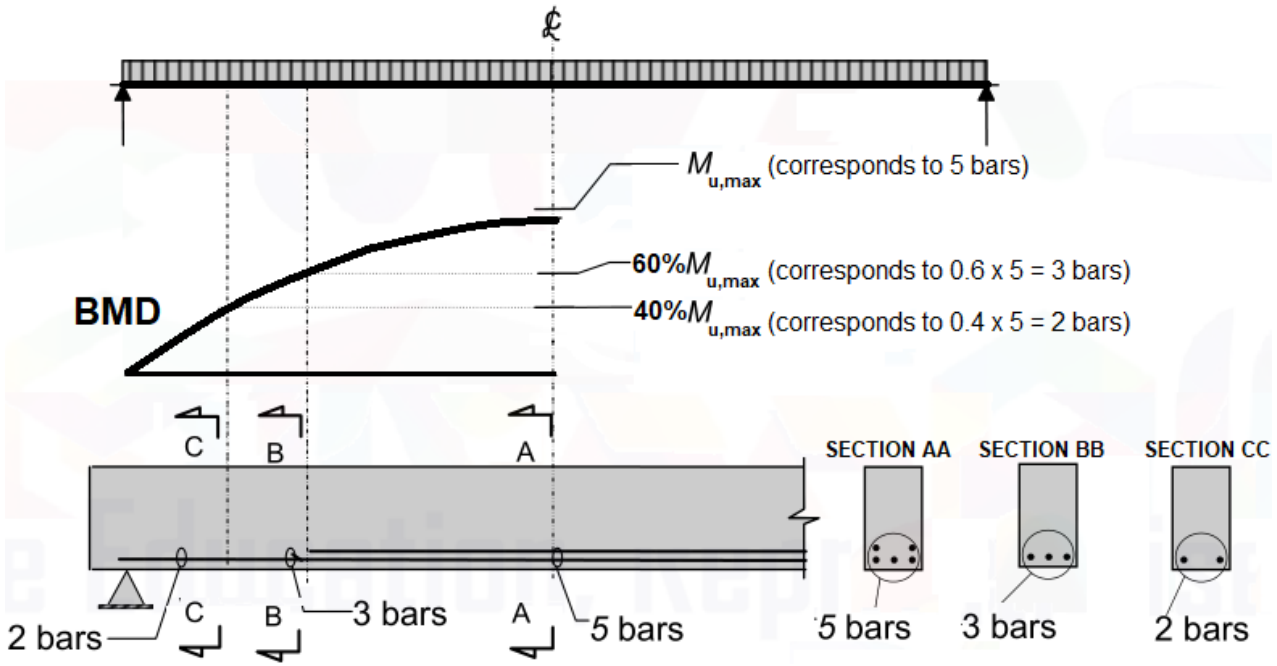
- A beam is designed for the section of maximum bending moment ($M_{u,max}$). Although the bending moment progressively decreases away from these critical sections, the same reinforcement (A_{st}) is provided throughout the beam for convenience.
- But for economical consideration, the tension reinforcement may be cutoff or "**curtailed**" progressively with decrease in bending moment.



Curtailment of Tension Reinforcement

Theoretical Bar Cut-off points:

- **Theoretical cut-off point** of a steel bar is that point beyond which it is (theoretically) no longer required to resist the design moment.
- We know that, design steel area A_{st} corresponds to the design moment $M_{u,max}$. Hence, at any section where bending moment $M_u = 60$ % of $M_{u,max}$, the steel area required is only 60 % of A_{st}, and the remaining 40 % steel may be cut off.



Splicing of Reinforcements

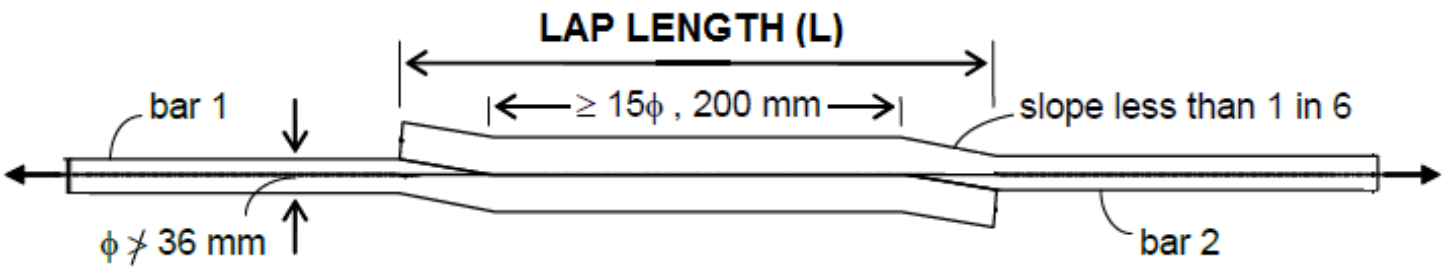
Definition:

- Splices are required when:
  - bars required are longer than available lengths, and hence needs to be extended.
  - the bar diameter has to be changed along the length.
- The purpose of splicing is to transfer effectively the axial force from the terminating bar to the connecting (continuing) bar. This invariably introduces stress concentrations in the surrounding concrete.
- As per IS456,
  - splices in flexural members should not be at sections where the bending moment is more than 50 percent of the moment of resistance.
  - not more than half the bars shall be spliced at a section.

Splicing of Reinforcements

Methods of splicing:

1. **Lap Splice**[Refer Cl. 26.2.5.1]
   - Only for bars of dia $\phi \leq 36$ mm
   - Lap length L =
     - $\geq$ Ld or 24 ϕ, for bars in compression
     - $\geq$ 2Ld or 30 ϕ, for bars in tension



2. **Weld Splice**[Refer Cl. 26.2.5.2]
   - For bars of dia $\phi > 36$ mm
   - Butt welding is generally adopted.

THANK YOU